Soiling in concentrating solar thermal power (CSP) – effects and connection to PV

German Aerospace Center (DLR), Plataforma Solar de Almería, Spain

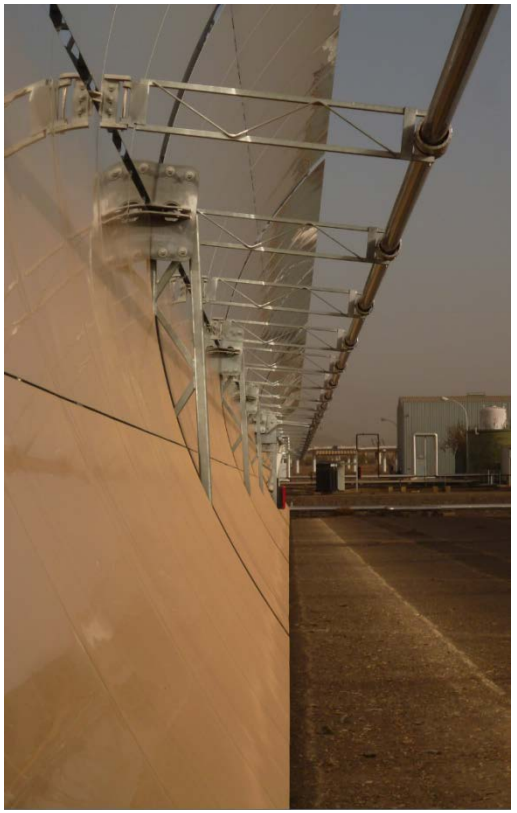
Fabian Wolfertstetter, Stefan Wilbert, Natalie Hanrieder, Lothar Keller, Sergio Gonzalez Rodriguez, Pascal Kuhn, Bijan Nouri

fabian.wolfertstetter@dlr.de

+34 950611877

Outline

- Short introduction to concentrating solar technology
- Optical differences CSP-PV and implications for soiling
- Mie based optical model
- Soiling measurements
- Cleaning strategies
- Outlook



Pictures: DLR, Plataforma Solar

Our Partners:

UNIVERSIDADE DE ÉVORA

BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación

TECHNISCHE UNIVERSITÄT DRESDEN

GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

IRESEN Institut de Recherche en Energie Solaire et en Energies Nouvelles

masen

DLR

DLR Energy meteorology group at CIEMAT's Plataforma Solar de Almería, the largest CSP research facility

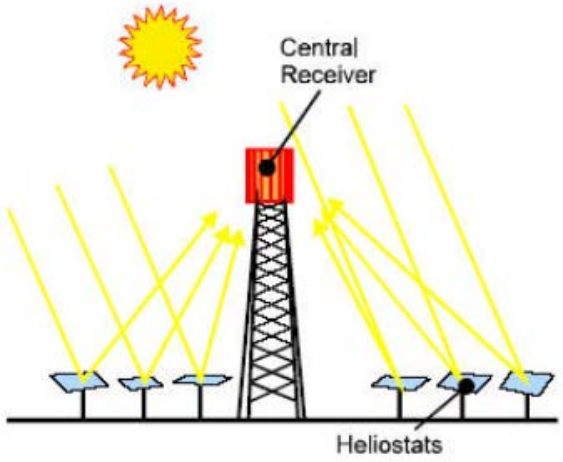
Research topics in CSP and PV:

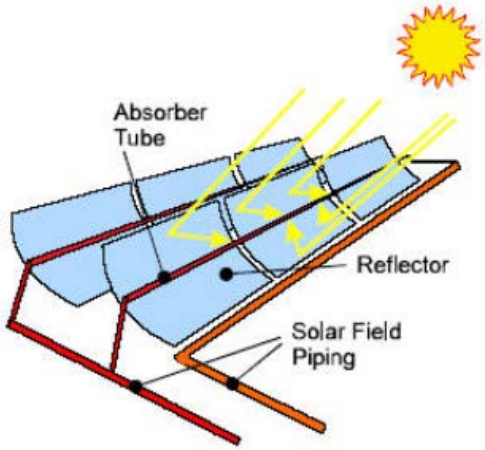
- Soiling
- Degradation & abrasion of solar materials
- Attenuation of radiation
- Circumsolar radiation
- All-sky imager based nowcasting
- Shadow camera based measurements
- Atmospheric measurements

http://www.dlr.de/sf/en/desktopdefault.aspx/tabid-10224/17488_read-44933/

DLR

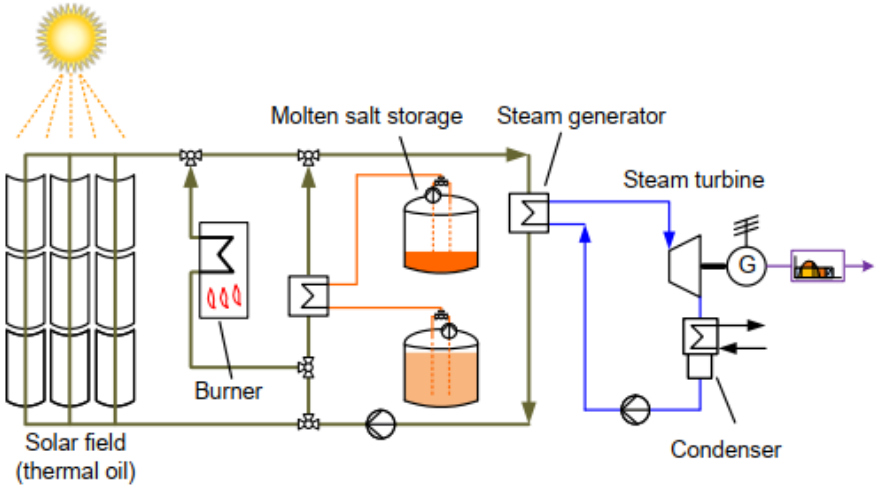
Concentrating Solar Power



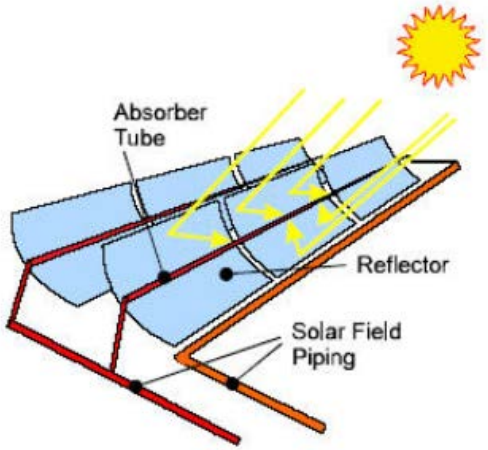


Images property of: Torresol energy, MASEN, SolarPACES

Concentrating Solar Power



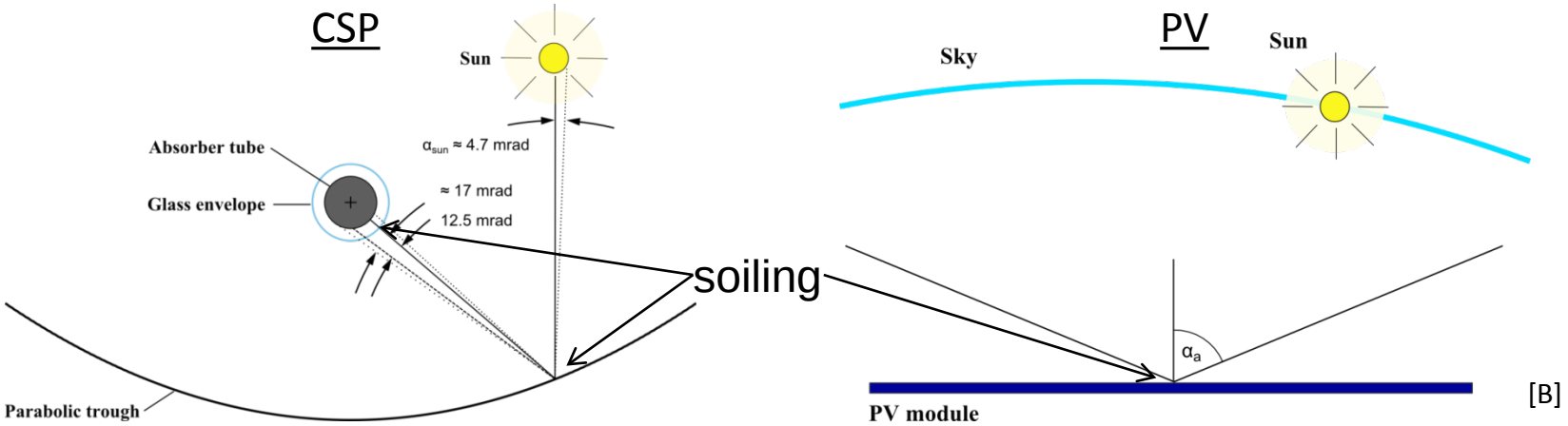
- Concentration of direct sunlight with mirrors to achieve high temperatures
- Provision of electricity (turbine cycle), process heat, desalination
- CSP uses only **direct component** of solar irradiation
- Cost effective **thermal storage** option
- **Grid stabilizing** effect thanks to turbine



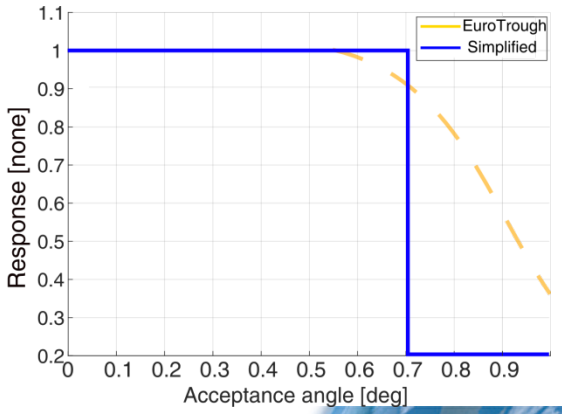
Images property of: Torresol energy, MASEN, SolarPACES, [T]

Optics

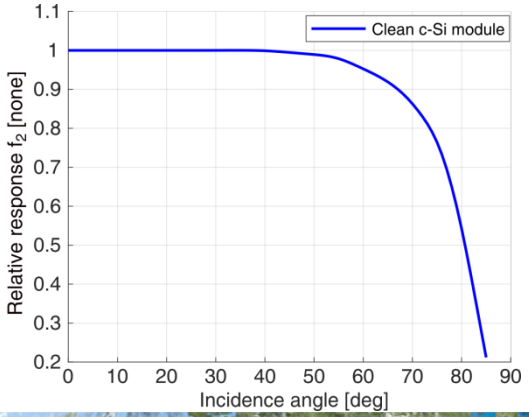
- CSP only harvests direct component within a small acceptance angle



[B]



[Wi],[W1]

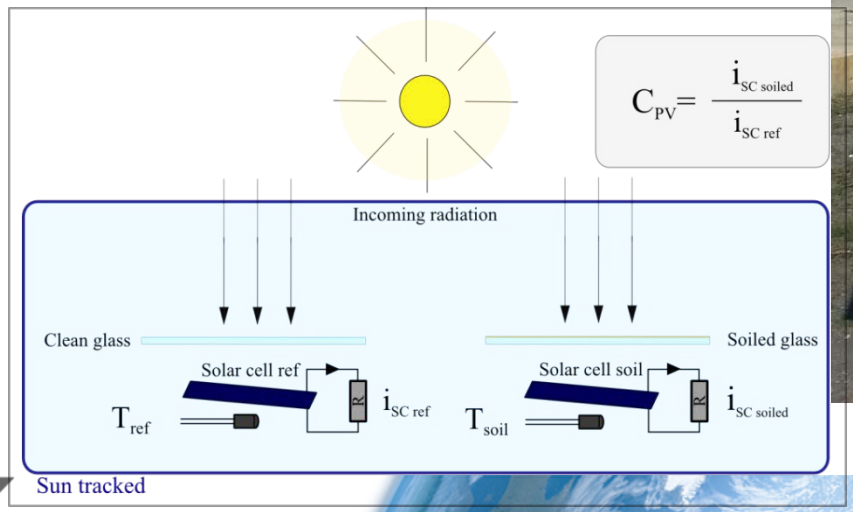


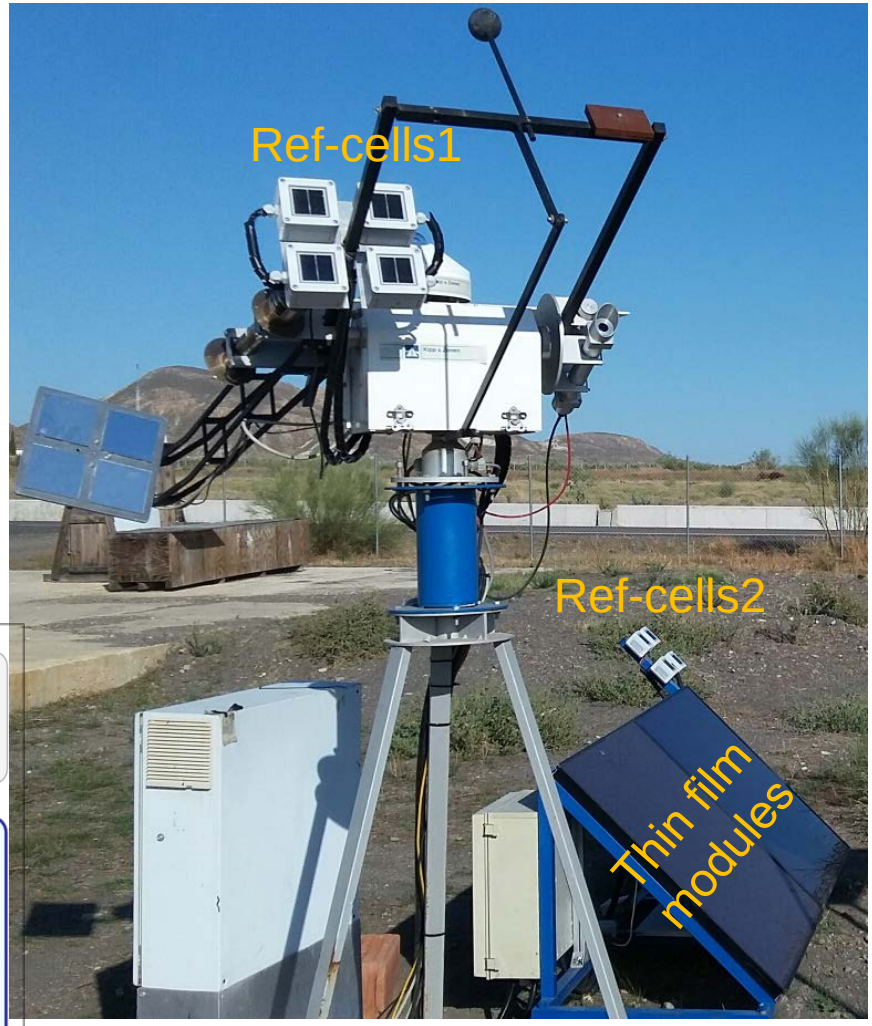
[K]

Measurement of soiling

PV

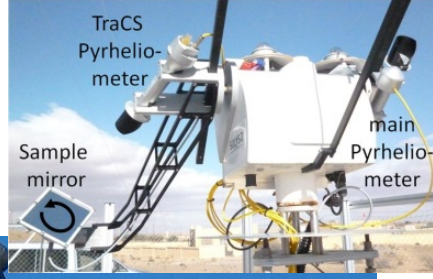
- Short circuit current of sample cells / modules
- „Cleanliness“ = $I_{SC,soiled}$ / $I_{SC, clean}$
- Measurement:
  - Reference cell I_{SC}
- 2 years of measurements at PSA





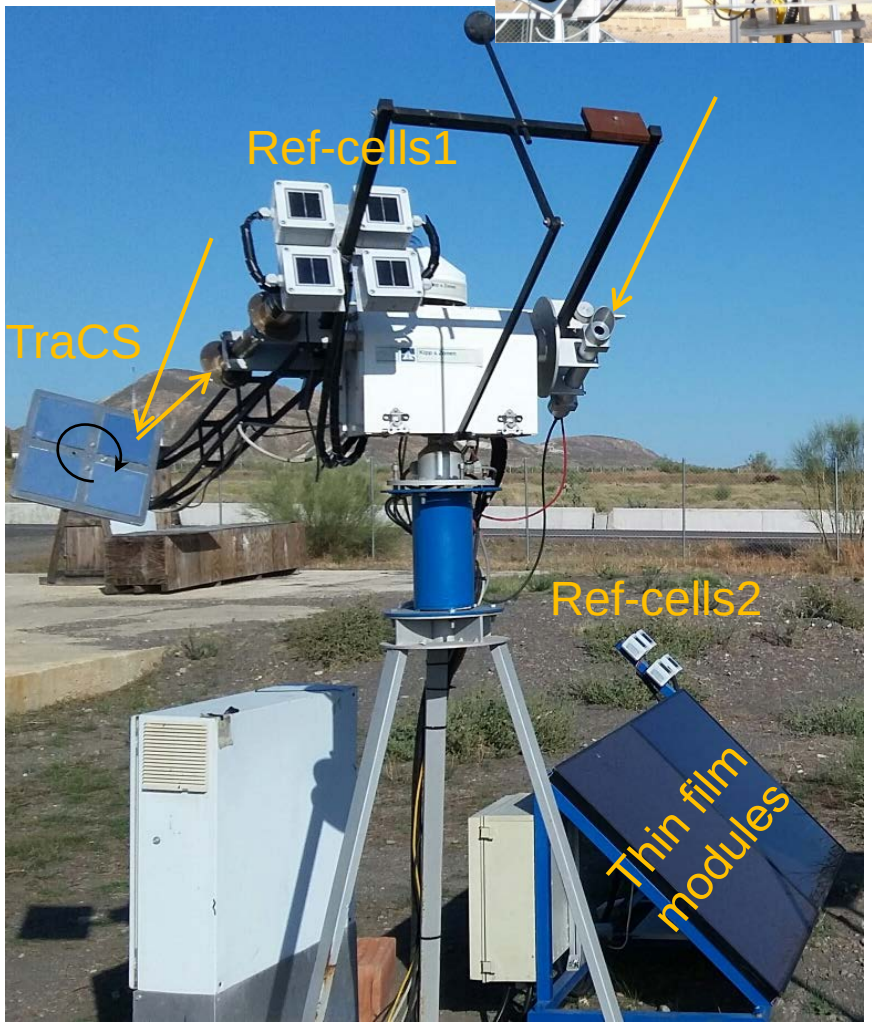
Images: DLR

Measurement of Soiling

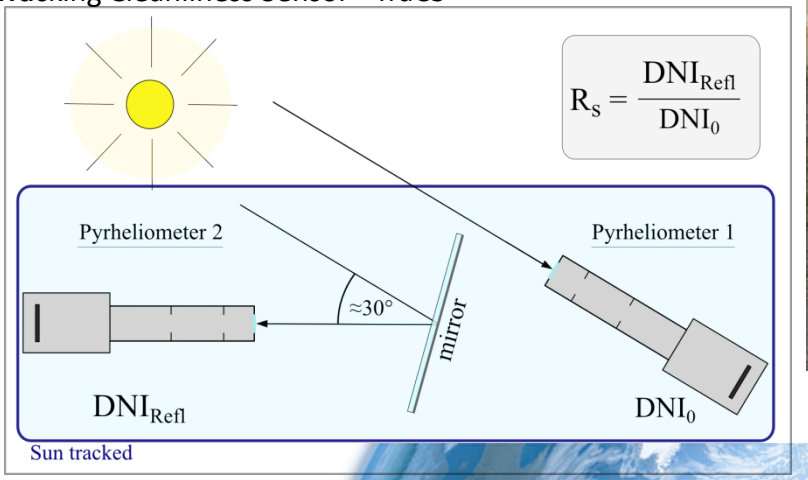


CSP

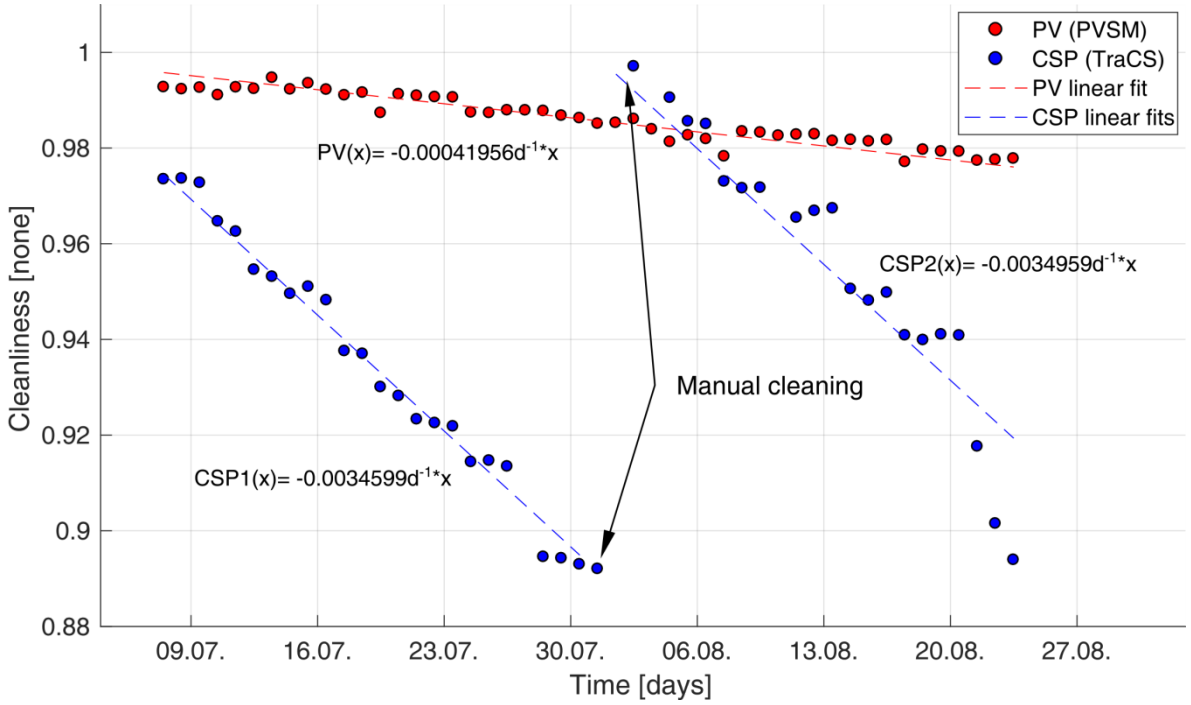
- Solar weighted specular reflectance ρ
- Cleanliness = ρ_{soiled} / ρ_{clean}
- TraCS: [W3]
  - Parallel real time measurement of 4 samples
  - Sun as light source
  - Rotation to increase measurement spot
- Handheld or lab devices [FG]
- 5 years of CSP soiling data at PSA



Tracking **C**leanliness **S**ensor - TraCS



Comparison of soiling

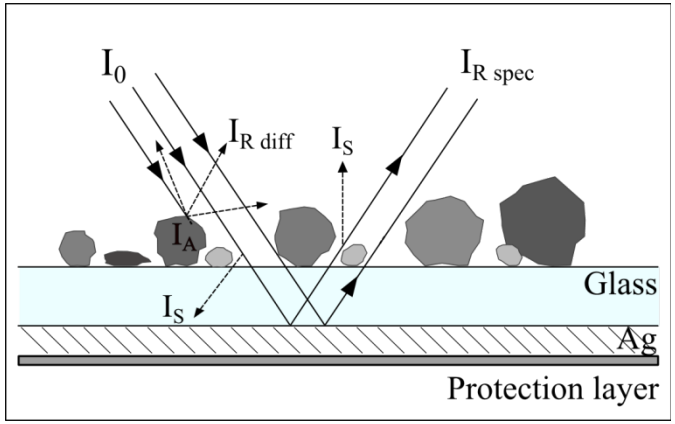


→ CSP soiling rate approx. **8-9 times higher** than PV (0.35%/d and 0.04%/d)

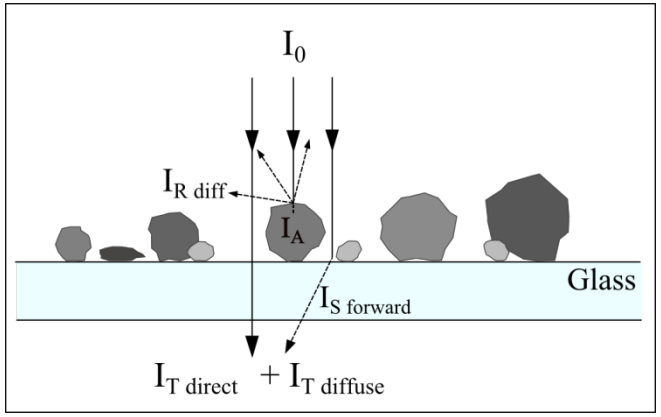
→ Assumption: same surface densities

Optics and soiling

CSP: Glass-silver mirror



PV: Glass transparent cover



Images: [B]

- In **both technologies** optical losses occur due to:
  - Diffuse reflection
  - Scattering
  - Absorption

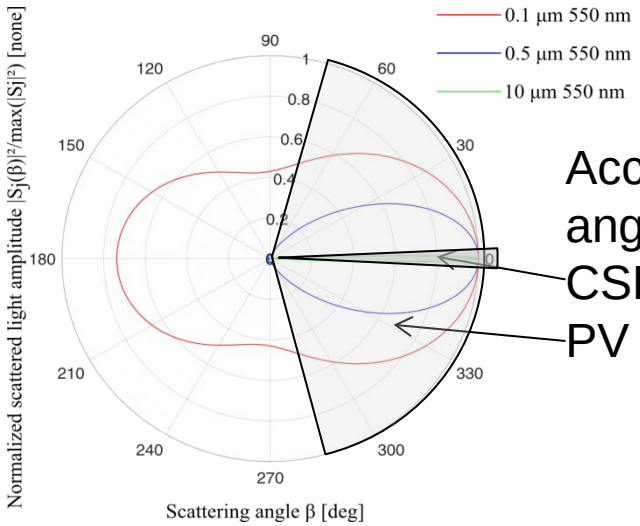
CSP:

- 2 passages through the soiling layer
- 1 passage through the (soiled) absorber tubes glass cover
- Most forward scattered light is lost

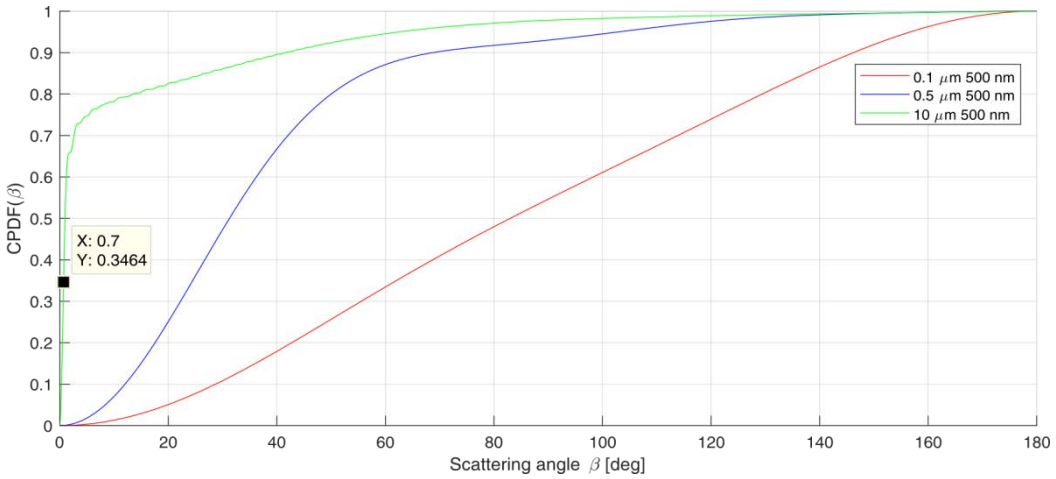
PV:

- 1 passage through the (soiled) glass cover
- Most forward scattered light is NOT lost

Optical model assumptions

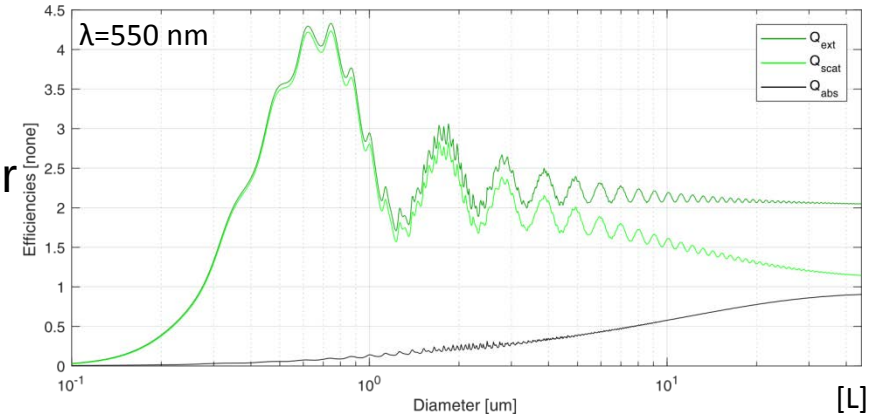


Acceptance angles for CSP and PV



Assumptions:

- Spherical particles
- Size distribution and refractive index for Saharan dust from literature [F], [Wa]
- Single interactions (no conglomeration)
- Low soiling levels! (<1 g/m²)

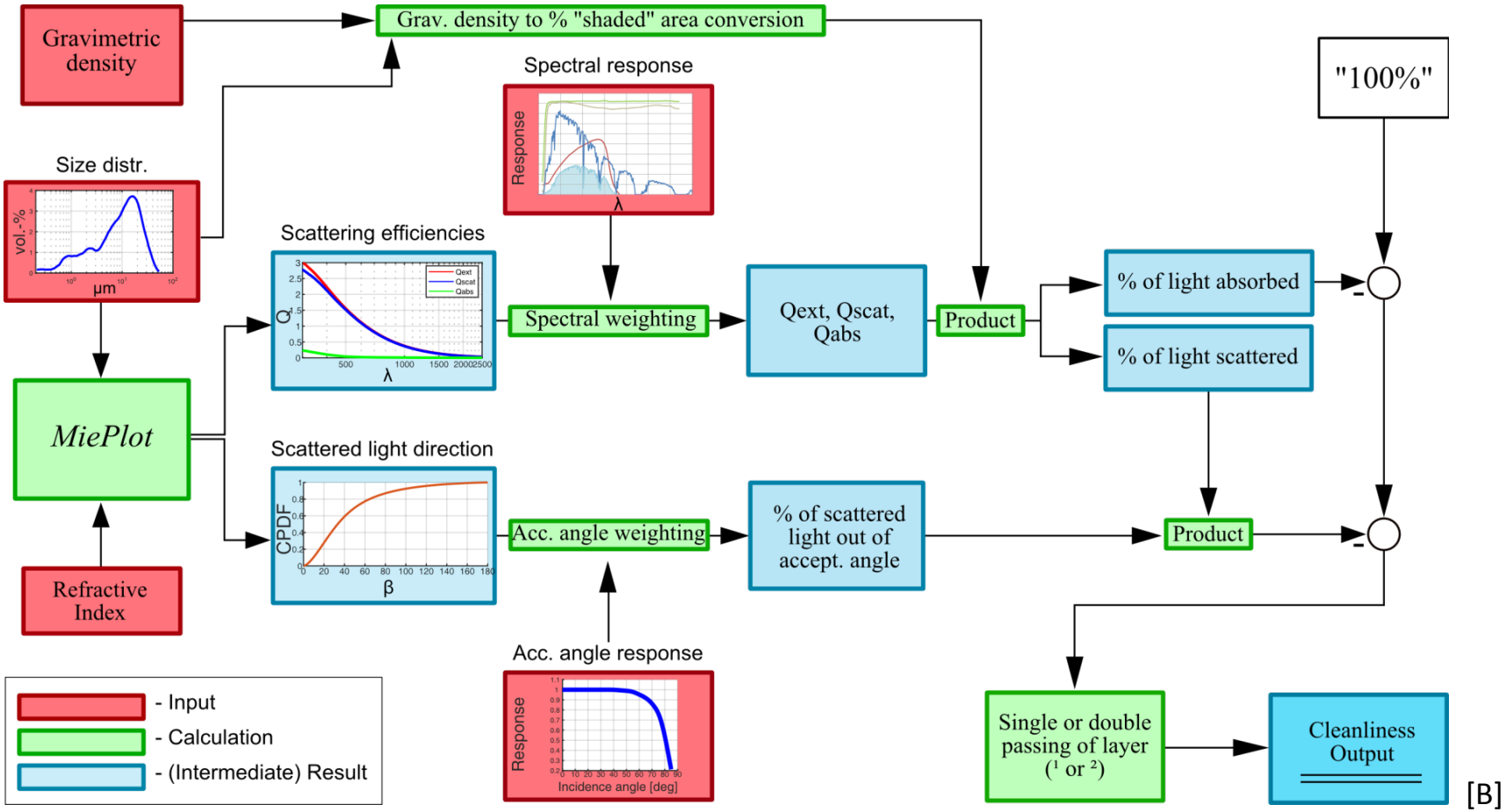


[L]

Optical model scheme

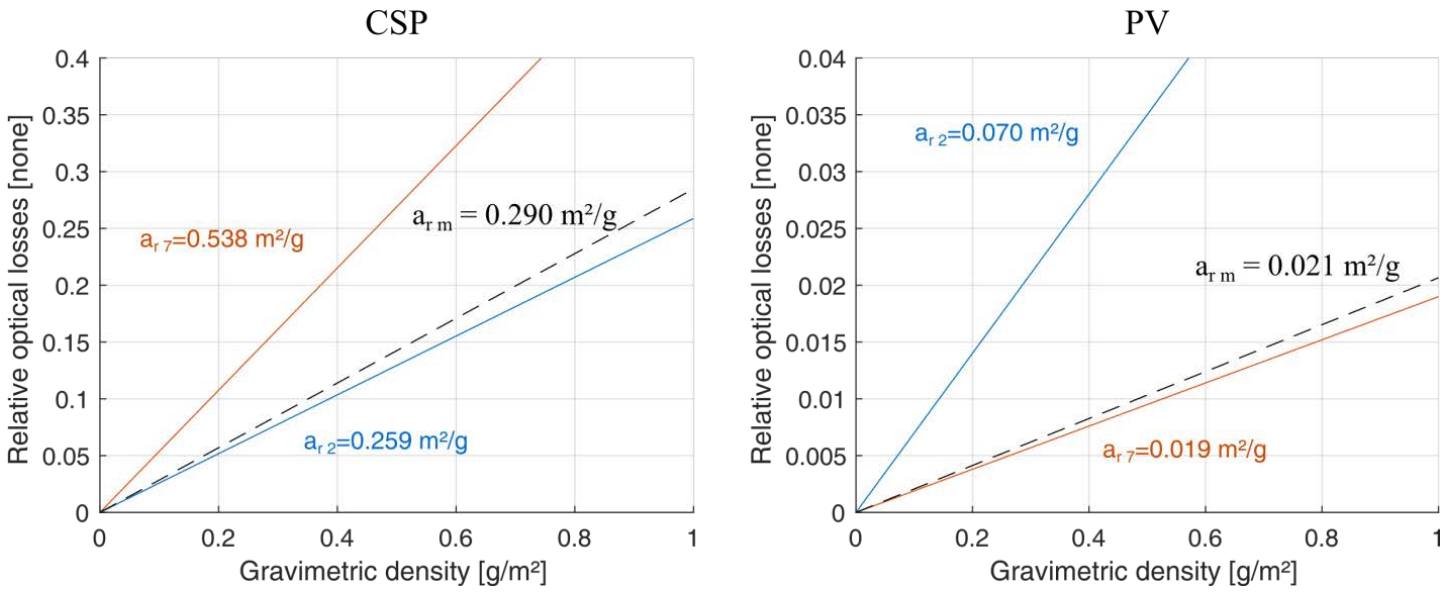
$$C_{\mathrm{CSP}} = \left(1 - k_{\mathrm{a\ cov}} \cdot \left(Q_{\mathrm{abs\ CSP}} + Q_{\mathrm{scat\ CSP}} \cdot \left(1 - \int_0^{180°} \frac{\mathrm{d}CPDF(\beta)}{\mathrm{d}\beta} \cdot W_{\mathrm{CSP}}(\beta)\,\mathrm{d}\beta\right)\right)\right)^2 \tag{4.6}$$

$$C_{\mathrm{PV}} = 1 - k_{\mathrm{a\ cov}} \cdot \left(Q_{\mathrm{abs\ PV}} + Q_{\mathrm{scat\ PV}} \cdot \left(1 - \int_0^{180°} \frac{\mathrm{d}CPDF(\beta)}{\mathrm{d}\beta} \cdot W_{\mathrm{PV}}(\beta)\,\mathrm{d}\beta\right)\right) \tag{4.7}$$



[B]

Optical model results



- Modelled data (black dashed) lies within the range of measured data (red and blue lines)
- Tendency for underestimation in accordance with:
  - assumed size distribution (grav. dens. → %-covered)
  - assumed spherical particles (real particles = aspect ratio)
  - neglect of conglomeration (larger structures = diff. reflection & absorption) [B]

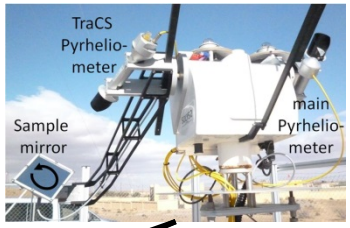
[S], https://www.dlr.de/sf/en/desktopdefault.aspx/tabid-8680/12865_read-32404/

enerMENA network **Operational since 2010 -2013**

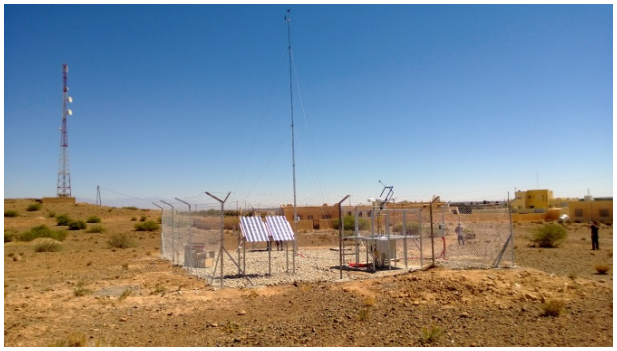
12 meteorological measurement stations (solar irradiance, temperature, pressure, relative humidity, wind, etc…)

Scatterometer FS11from Vaisala

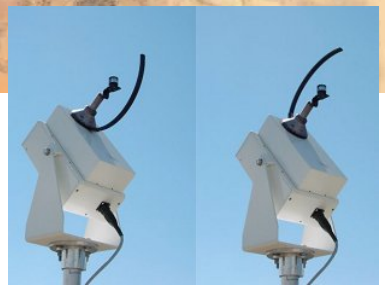
Grimm EDM164 Particle counter



TraCS for mirrror soiling

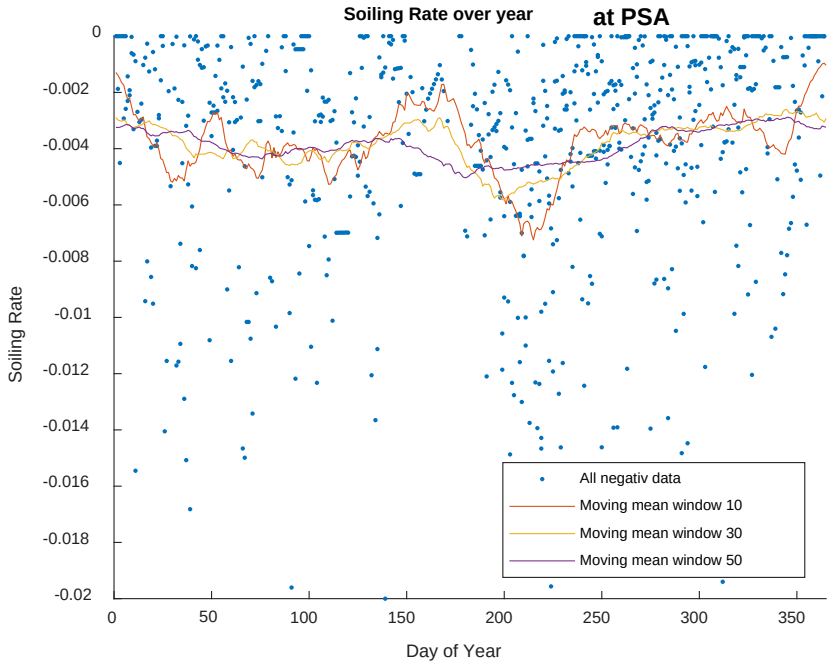


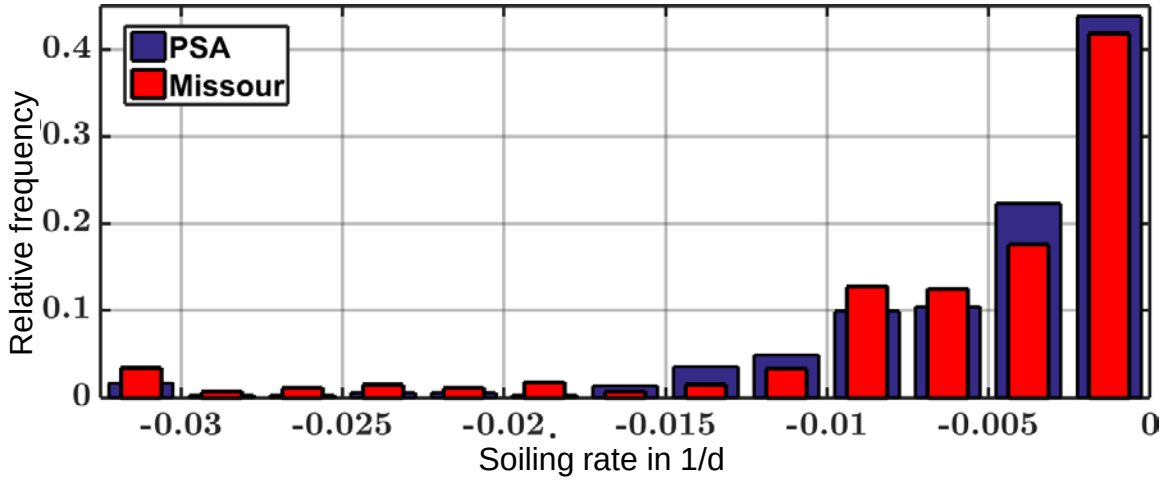
HVS-TSP16 from MCZ: gravimetric measurement principle

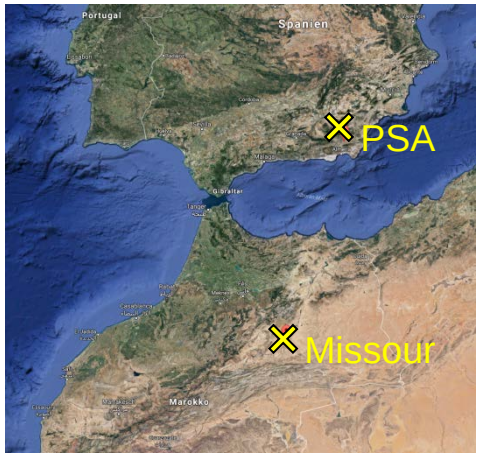


Soiling rate: site comparison

- Soiling rate strongly depends on time and location
- Little CSP-specific information available in target regions for solar projects
- Efforts to estimate soiling rate from other weather parameters – next webinar!





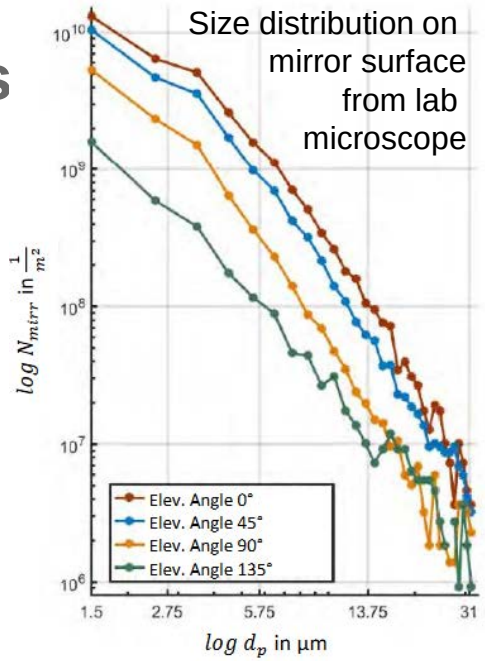


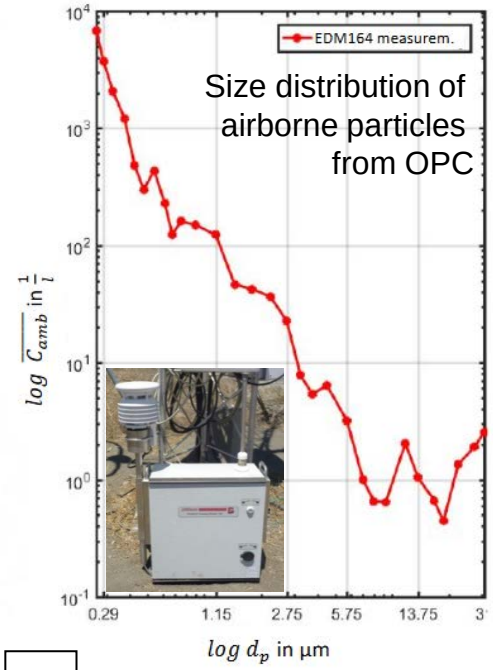
Particle size distributions in air and on surface

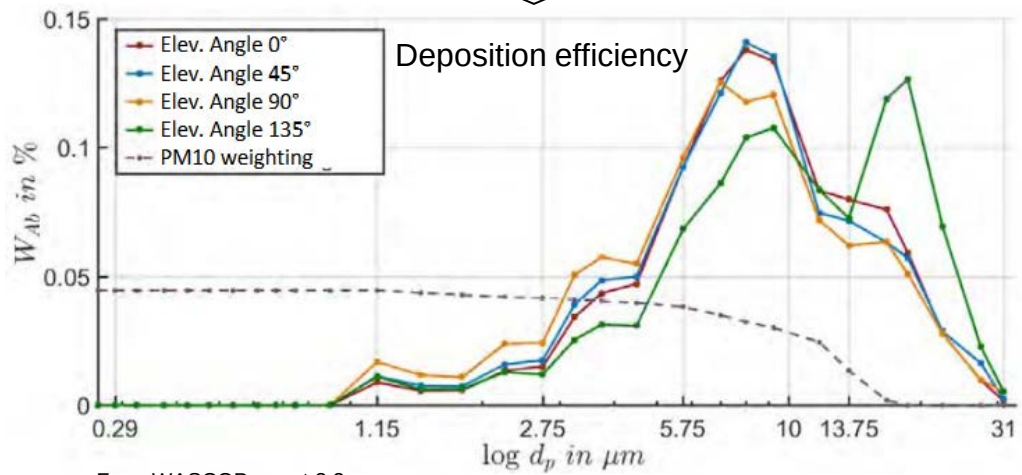
- Microscope analysis shows different „deposition efficiencies“ for different exposure periods:

$$E_{dep} = \frac{N_{p,surf}(d_p)}{C_{p,amb}(d_p)} =$$

$$= \frac{\text{Part. Size distribution on surface}}{\text{Size resolved Part. concentration in amb. air}}$$



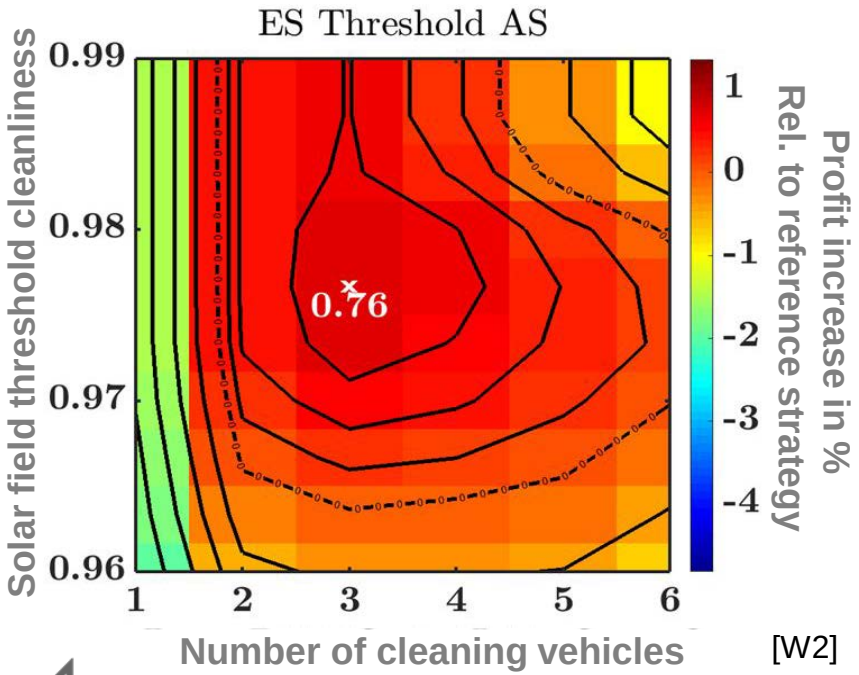




From WASCOP report 3.2:
http://wascop.eu/wp-content/uploads/2018/06/WASCOP_deliverable_3.2_final_plainText.pdf

Cleaning optimization

- Trade-off between **cleaning cost** minimization and **revenue** maximization
- **Time resolved soiling rate and irradiance** information are both necessary to fully simulate effects of cleaning
- Adaptation of cleaning intensity on cleanliness **increases profit** significantly
- Better performance achieved with reinforced learning algorithm



[W2]

Image: Abengoa Solar

Conclusion and outlook

- Soiling is an issue in all solar technologies
- CSP is more affected by soiling
- Given the particle properties, the efficiency reduction can be modelled for CSP and PV
- Long term measurement campaigns of soiling
- Cleaning strategy optimization can increase profit of a project

Next webinar (Sept. 11):

Soiling model that derives the soiling rate from weather parameters (aerosol number size distribution, relHum, temp, wind, etc.)

Thank you for your attention

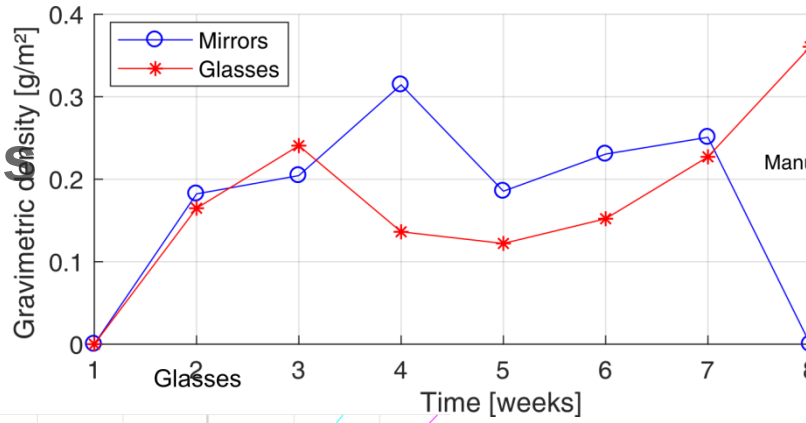
fabian.wolfertstetter@dlr.de

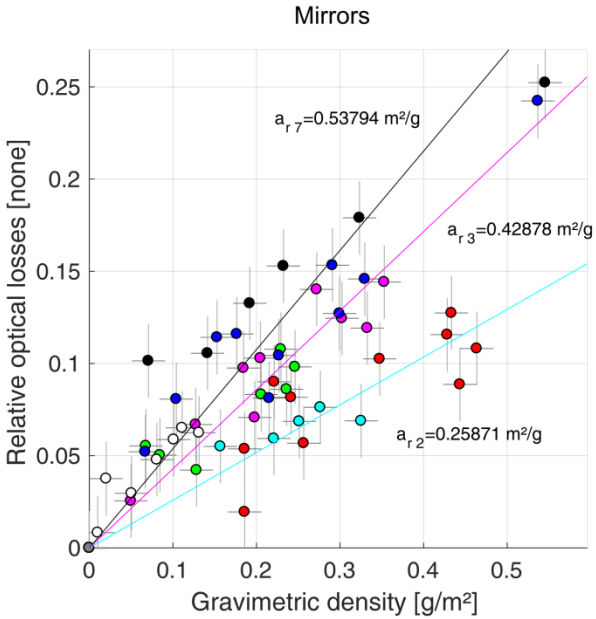
DLR

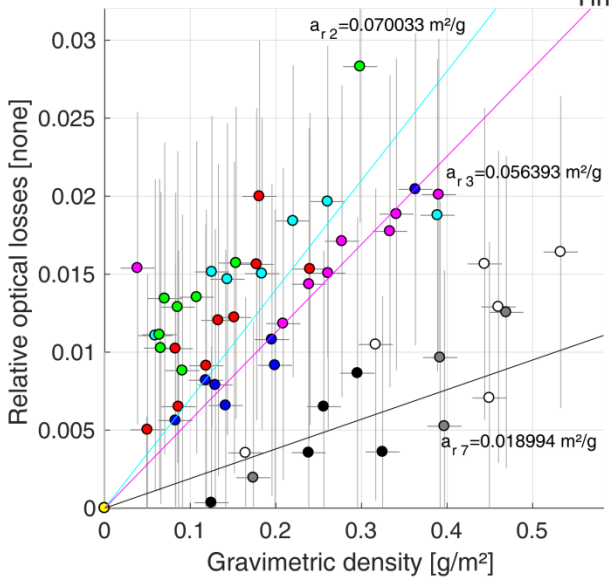
References

- [Wi] **Wilbert**, S.: *Determination of Circumsolar Radiation and its Effect on Concentrating Solar Power.* PhD thesis, Technische Hochschule Aachen, 2014.
- [W1] **Wolfertstetter**, F.*: Effects of soiling on concentrating solar power plants.* PhD thesis, Technische Hochschule (RWTH) Aachen, 2016
- [K] **Knisely**, B., S. V. **Janakeeraman**, J. **Kuitche** . G. TamizhMani: *Validation of Draft International Electrotechnical Commission 61853-2 Standard: Angle of Incidence Effect on Photovoltaic Modules.* Arizona State University, Photovoltaic Reliability Laboratory, 2013.
- [L] **Laven**, P.: *MiePlot - A computer program for scattering of light from a sphere using Mie theory & the Debye series.* Computer Program, 2017.
- [Wa] **Wagner**, R., T. **Ajtai**, K. **Kandler**, K. Lieke, C. Linke, T. Müller, M. Schnaiter . M. Vragel: *Complex refractive indices of Saharan dust samples at visible and near UV wavelengths: a laboratory study. A*tmospheric Chemistry and Physics, 12(5):2491–2512, mar 2012.
- [F] **Figgis**, B.: *PV Soiling: Qatar Perspective.* DEWA Soilingworkshop 2016*, 2016*
- **[T] THERMVOLT Systemvergleich von solarthermischen und photovoltaischen Kraftwerken für die Versorgungssicherheit Schlussbericht 01.11.2014 - 30.06.2016**
- [B] Bellmann, P., Oct. 2017, „**Investigation of soiling on mirror and glass samples with regard to power losses in CSP and PV technologies**“, Diploma thesis, University of Dresden
- [Sc] Schüler, David, et al. "The enerMENA meteorological network–Solar radiation measurements in the MENA region." AIP Conference Proceedings. Vol. 1734. No. 1. AIP Publishing, 2016.
- [W2] Wolfertstetter F, Wilbert S, Dersch J, Dieckmann S, Pitz-Paal R, Ghennioui A. Integration of Soiling-Rate Measurements and Cleaning Strategies in Yield Analysis of Parabolic Trough Plants. ASME. J. Sol. Energy Eng. 2018
- [W3] Wolfertstetter, F., Pottler, K., Alami, A., Mezrhab, A., & Pitz-Paal, R. (2012). A novel method for automatic real-time monitoring of mirror soiling rates. SolarPACES 2012.
- [FG] A. Fernández-García, F. Sutter, L. Martínez-Arcos, C. Sansom, F. Wolfertstetter, C. Delord, Equipment and methods for measuring reflectance of concentrating solar reflector materials, Solar Energy Materials and Solar Cells, Volume 167, 2017
- [S] Schüler, David, et al. "The enerMENA meteorological network–Solar radiation measurements in the MENA region." AIP Conference Proceedings. Vol. 1734. No. 1. AIP Publishing, 2016.
- [W4] Wolfertstetter et al, „Soiling and Condensation model applied to CSP solar field“, WASCOP project report 3.2, 2018, http://wascop.eu/wp-content/uploads/2018/06/WASCOP_deliverable_3.2_final_plainText.pdf

Gravimetric density vs cleanliness measurement data







→CSP soiling loss approx. **8 -14 times higher** than PV, for same grav. density

- Change in size distribution over time [6]: „coarse to fine“